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Validation Study of Operational Battlescale Forecast Model (BFM) Over Western Asian Regions

by Teizi Henmi, John W. Raby, John Cruncleton, and Jim Kratzer

ARL-TN-118 December 2002

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Validation Study of Operational Battlescale Forecast Model (BFM) Over Western Asian Regions

Teizi Henmi and John W. Raby
Computational and Informational Sciences Directorate, ARL

and

John Cruncleton and Jim Kratzer
Physical Sciences Laboratory
New Mexico State University

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1. Introduction

The Battlescale Forecast Model (BFM) is an operational mesoscale forecast model developed at the U.S. Army Research Laboratory.[1] It has been extensively used to make short-range forecasts of atmospheric conditions as a component in both the Integrated Meteorological System (IMETS) and the Computer Assisted Artillery Meteorology System. For prognostic calculation, the BFM uses the Higher Order Turbulence Model for Atmospheric Circulation developed by Yamada.[2]

After Operation Enduring Freedom started, a validation study of the BFM over model domains in western Asia became necessary to prepare for use of the BFM over Afghanistan. It would have been ideal to run the BFM on the model domain over Afghanistan; unfortunately, no meteorological data are presently available over Afghanistan. Therefore, two model domains in the same region, one over Iran and the other over Pakistan, were selected for the BFM validation study. Figure 1 shows approximate locations of model domains used for this study.

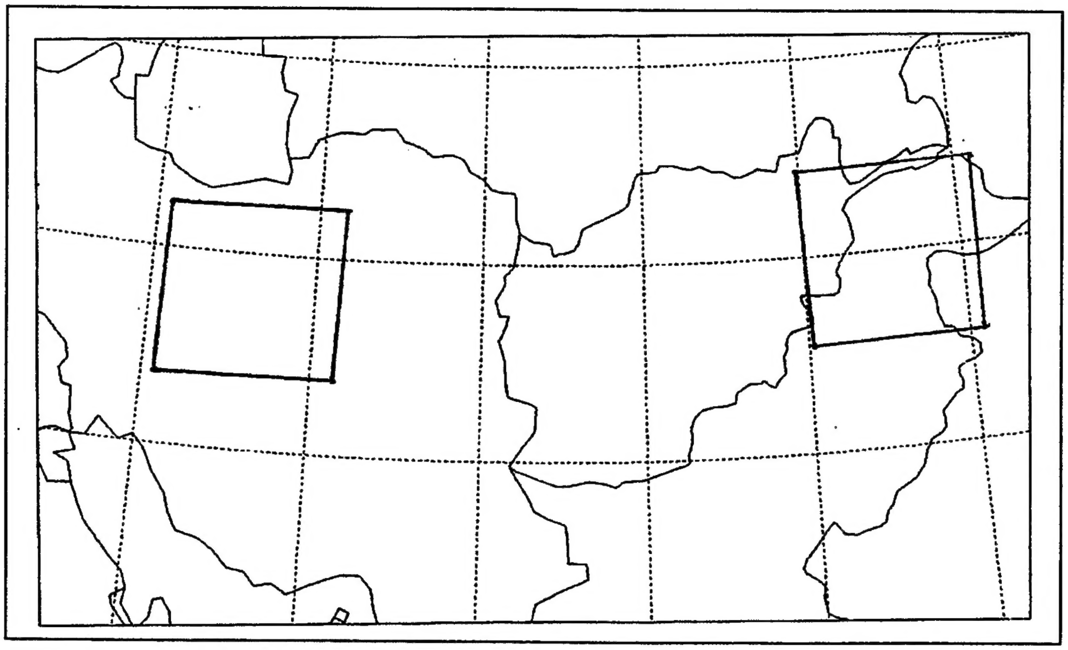


Figure 1. Approximate locations of model domains used for the BFM validation study. Each square covers the 500- × 500-km area.

[1] Henmi, T., and R. Dumais, Jr. "Description of the Battlescale Forecast Model (BFM)." ARL-TR-1032, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, 1998.

[2] Yamada, T., and S. Bunker. "A Numerical Model Study of Nocturnal Drainage Flows With Strong Wind and Temperature Gradients." *Journal of Applied Meteorology*, vol. 28, pp. 545–554, 1999.

For this study, scientists of the Physical Sciences Laboratory of New Mexico State University ran the BFM twice a day, at 00 and 12 universal time coordinate (UTC), and archived observed data available over the model domains. The BFM output and surface observation data were compared to validate the BFM. The study was based on the data obtained during October and November 2001. (The validated BFM was the one on the U.S Army IMETS ABCS_6_2_1_0.) Meteorological data, including surface and upper air data and Navy Operational Global Atmospheric Prediction System (NOGAPS) forecast data, were obtained from the U.S. Air Force Weather Agency using the Air Force Tactical VSAT System.

During the same period, surface wind field analysis data, model output by NOGAPS, Aviation Model (AVN), and Mesoscale Model Version 5 (MM5), were obtained from the U.S. Navy Meteorology and Oceanography Command through the Internet using the METCAT System. These data were compared with surface observation data archived as previously described.

The purpose of this report is to describe the results of statistical comparisons of the BFM forecast data with observation data and those of the NOGAPS, AVN, and MM5, with observation data over western Asia. It is noted that the present study is limited to the surface meteorological data and that because of the limited number of observation sites and data, the results should be regarded as qualitative.

2. Review

In the following, the validation studies done in the past are briefly reviewed. The forecast skill of the BFM was compared with that of MM5 by applying the models to the domain of White Sands Missile Range, NM, which covers a 167- × 167-km area (51 × 51 grid points, with 3.33-km grid spacing). Meteorological parameters forecasted by the models were compared with observed data. The comparison study showed that the forecast skills of the BFM were comparable to those of the MM5. Surface temperature forecasted by both the BFM and MM5 agreed well with observed values. Both the BFM and the MM5 showed difficulties for forecasting the relative humidity. For wind parameters, both models tended to predict wind speed less than that observed, but BFM calculations produced lower wind speed than the MM5. For wind direction, the BFM resulted in better forecasts than the MM5.[3]

The BFM in operational mode on the IMETS has been extensively used over the 500- × 500-km model domain, with grid spacing of 10 km. A statistical evaluation of the BFM in operational mode was conducted for cases during a 30-day period, with over three different model domains

[3] Henmi, T. "Comparison and Evaluation of Operational Mesoscale MM5 and BFM Over WSMR." ARL-TR-1476, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, 2000.

having different terrain complexities and climate (Colorado, Washington, and Florida).[4] The model calculations were initialized with the following three different sets of initial conditions:

(1) NOGAPS + upper air data + surface data,

(2) NOGAPS + upper air data, and

(3) NOGAPS.

Forecast data for 24-hr periods were statistically compared with surface observation data by calculating parameters such as mean difference (MD), absolute difference (AD), root mean square error (RMSE), root mean square vector error (RMSVE), and correlation coefficient (CC).

For all three model domains, the temperature fields of BFM initialized with (1) and (2) were statistically better than those initialized with (3). For Colorado and Washington model domains, the BFM showed clear tendencies of forecasting dew point temperature lower than those observed throughout the 24-hr forecast period. However, for the Florida model domain, forecasts of dew point temperature were higher than observed.

Three different types of initialization data did not produce significantly different wind fields throughout the 24-hr forecast period. The value of MD for wind speed was in the range of 0 to 1 m/s. And those of AD were also between 0 and 1 m/s for three model domains throughout the 24-hr forecast period.

For Colorado and Washington model domains where terrain was more complex than Florida, the use of the BFM improved temperature forecasts over those of NOGAPS and Navy Operational Regional Atmospheric Prediction System (NORAPS). For the Florida domain, no significant improvements in temperature forecasts were found. Similarly, the BFM produced better wind fields than NOGAPS and NORAPS over Colorado and Washington.

3. Model Domains for Present Study

The following two BFM domains were chosen for the present study:

(1) Iran, centered at 34.50 N and 52.98 E and

(2) Pakistan centered at 35.58 N and 72.72 E.

Each model domain covers a 500- × 500-km area, with 10-km horizontal grid spacing and 51 × 51 horizontal grid number. The vertical depth of the model is 7 km above the highest point of the model domain, with 16 vertical layers.

[4] Henmi, T. "Evaluation Study of an Operational Mesoscale Forecast Model Over Three Climatologically Different Areas." ARL-TR-1034, U.S. Army Research Laboratory, Aberdeen Proving Ground, MD, 2000.

The complexities of the two model domains are summarized in Table 1. For comparison, the complexity data of the same size area centered at Kabul, Afghanistan is also given.

Table 1. Terrain complexities of the three domains.

Terrain (m)	Iran	Pakistan	Afghanistan
Mean elevation	1237	2991	2232
Max. height	3744	6717	6413
Min. height	-28	247	173
Standard dev.	642	1513	1153

As seen in Table 1, the Pakistan model domain is the most complex, containing high peaks of the Hindu Kush Mountain range in the northern part of the model domain. Compared to the Pakistan model domain, the Iran model domain is more flat, with the Caspian Sea below zero level at the northern part of the domain. As far as the complexity is concerned, the 500- × 500-km area of Afghanistan centered at Kabul is fairly complex, similar to the Pakistan model domain.

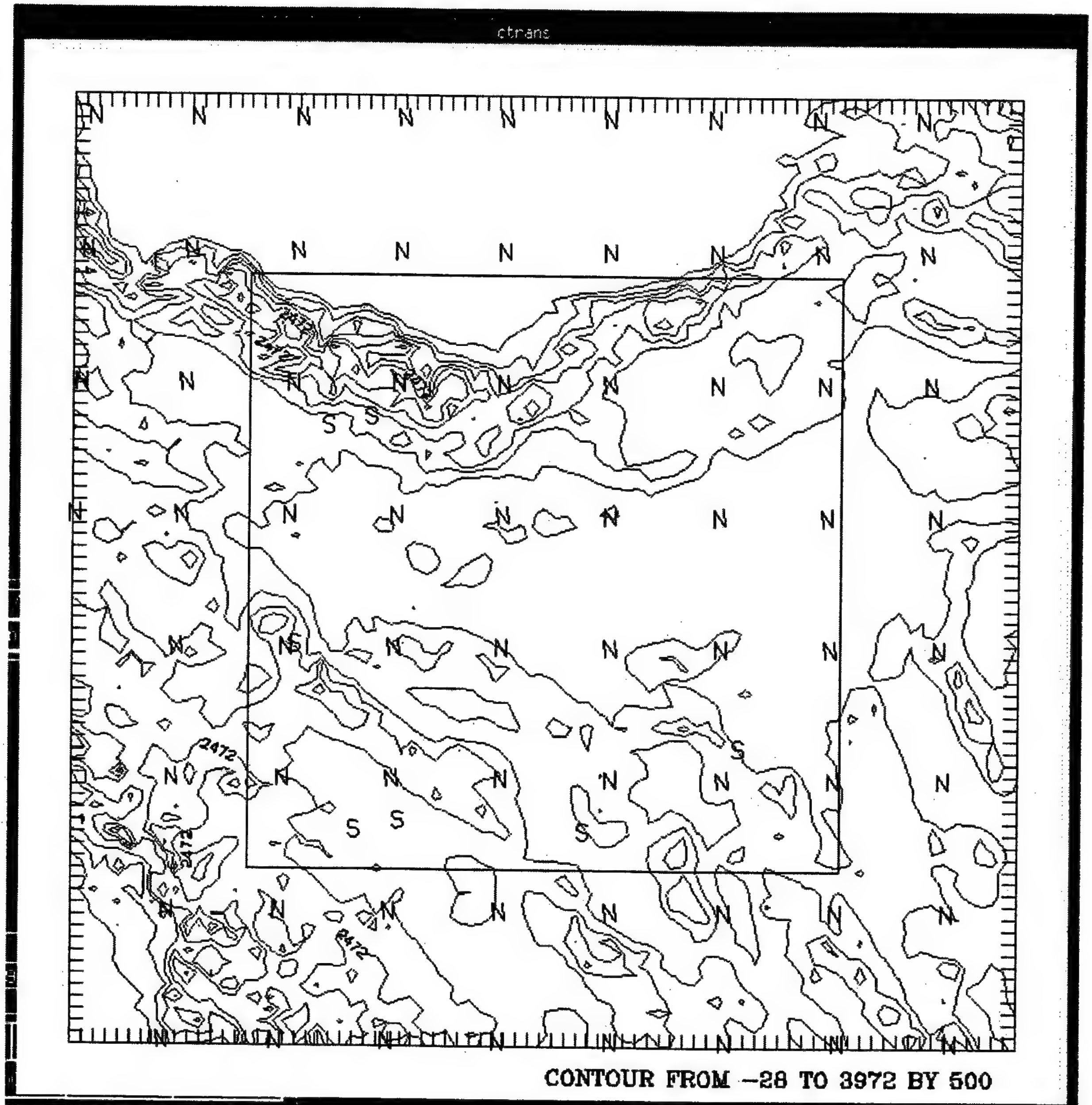
Figures 2 and 3 are the elevation contour maps of, respectively, the Iran and Pakistan model domains. In these figures, the outside squares cover the NOGAPS analysis and data composite area of 800 × 800 km, and the inside square covers the model domains of 500 × 500 km. In these figures, N and S represent the locations of the input data for model initialization of the model calculation. There were a few upper air-sounding stations in the surrounding areas for both domains, but because of incomplete form of the data sets, they were not used to initialize the BFM throughout the study period for both domains.

In Figure 2, there are seven stations of surface observations which are used to compare with the BFM forecast data. However, there is only one surface station in Figure 3 used for this study. Therefore, the statistical results obtained from the Pakistan model domain should be regarded as semiquantitative.

4. Method

4.1 Study Period

The study was initiated immediately after the commencement of Operation Enduring Freedom. Table 2 shows the date and initialization times of the BFM for this study. For most of the days when the BFM was run, the BFM was initialized at 00 and 12 UTC for 24-hr forecasts.



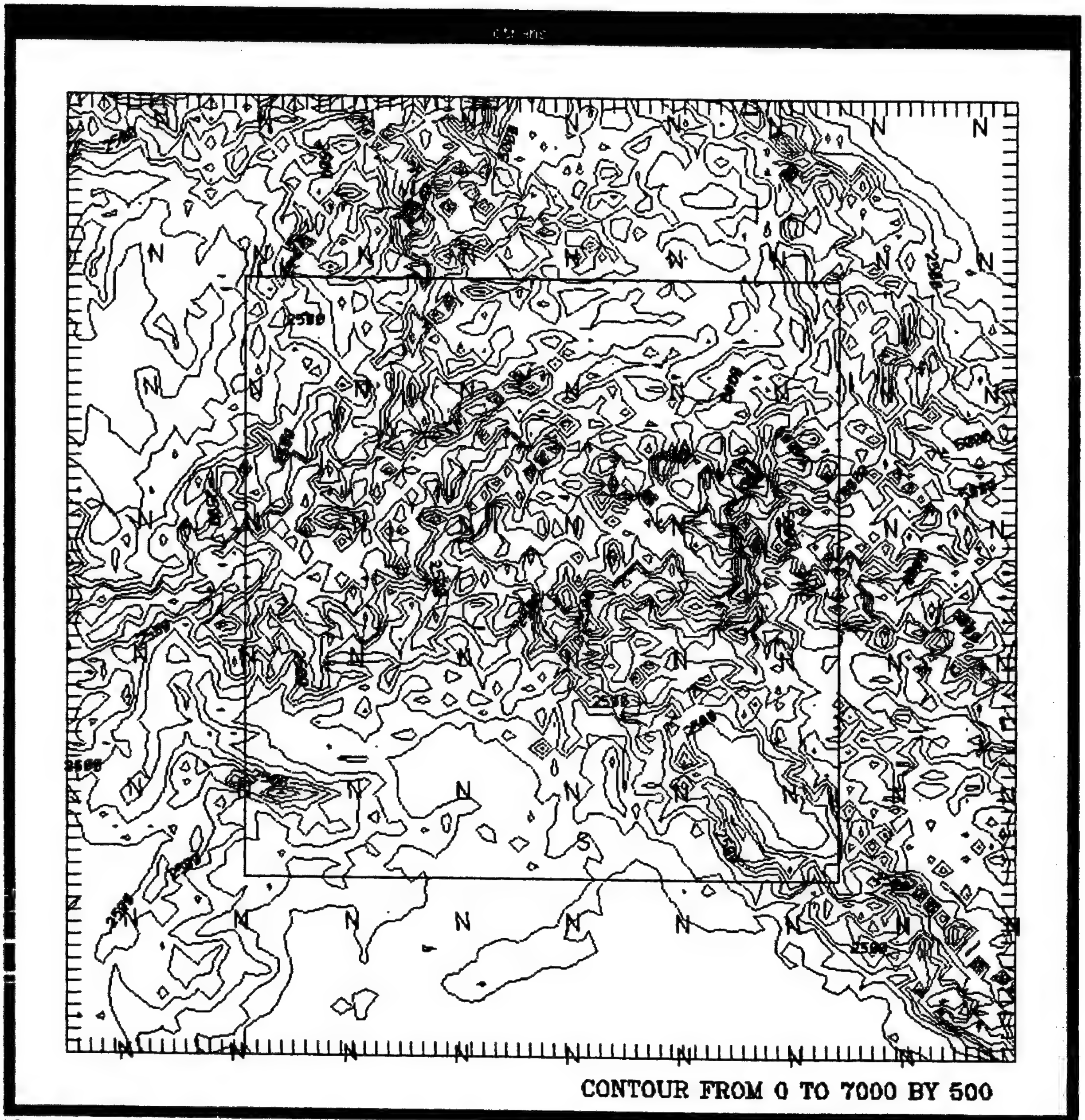
Notes: The outside area covers 800 × 800 km, and the inside area covers 500 × 500 km.
N = NOGAPS data points.
S = surface observation locations.

Figure 2. Elevation contours of the Iran model domain.

4.2 Forecast Method

Forecast calculation of the BFM is currently done as follows:

- From NOGAPS forecast data, horizontal wind vector components, temperature, dew point temperature, and geopotential height at 13 different pressure levels (1000, 975, 925, 900,



Notes: N = NOGAPS data points.
S = surface observation locations.

Figure 3. Elevation contours of the Pakistan model domain.

850, 700, 500, 400, 300, 250, 200, 150, and 100 mb) are obtained for the forecast periods of 0, 6, 12, 18, and 24 hr. These data are interpolated to the 81 × 81 grid, with grid spacing of 10 km at each pressure level for the forecast periods. The data is then vertically interpolated from the pressure levels to the BFM's height levels to produce four-dimensional fields (x, y, z, t) of the input data for initialization and lateral boundary data.

Table 2. Date and initialization time of the BFM run.

Date	Iran		Pakistan	
	00 UTC	12 UTC	00 UTC	12 UTC
October 2001	5, 9, 10, 11, 15, 16, 17, 18, 23, 24	12, 15, 16, 17, 18, 23, 24	9, 10, 11, 15, 16, 17, 18, 23, 24	9, 10, 11, 15, 16, 17, 18, 22, 23, 24
November 2001	14, 15, 19, 20, 26, 27, 28, 29, 30	8, 15, 18, 27, 28, 29, 30	14, 18, 19, 20, 26, 27, 29, 30	8, 13, 15, 19, 20, 27, 28, 29, 30

- Suppose a forecast calculation is initialized at time t_0. A precalculation will start at time $t_0 - 3$ hr; and for 3 hr from $t_0 - 3$ to t_0, the model fields are dynamically adjusted to the initial fields by the nudging method.
- The hourly lateral boundary condition data between two different forecast periods are calculated by a linear interpolation method.
- From time t to t + 1, the data for t + 1 are assimilated in for 1 hr; this process is repeated for an entire forecast period.

4.3 Data Comparison Method

After the forecast calculation is completed, the following bilinear interpolation is conducted to obtain the BFM data at the surface observation locations:

- Suppose a surface observation location (x' and y') is surrounded by four BFM grid points. An interpolated value φ' of an arbitrary variable φ at (x', y') is calculated using a bilinear interpolation method as follows:

$$\varphi_1 = \varphi(i, j) + (x' - x)[\varphi(i + 1, j) - \varphi(i, j)]. \quad (1)$$

$$\varphi_2 = \varphi(i, j + 1) + (x' - x)[\varphi(i + 1, j + 1) - \varphi(i, j + 1)]. \quad (2)$$

$$\varphi'(x', y') = \varphi_1 + (y' - y)[\varphi_2 - \varphi_1]. \quad (3)$$

Here (i, j) is the southwest grid point of the four grid points surrounding a surface observation location (x', y'), and (x, y) is the location for the grid point (i, j); φ(i, j) is an arbitrary variable at (x, y).

5. Statistical Parameters

The following statistical parameters between the BFM forecast data and surface observation data are calculated using the data available in the cases given in Table 2. The parameters are calculated for the forecast periods 0, 3, 6, 9, 12, 15, 18, 21, and 24-hr and for the entire period. Statistical parameters are calculated for temperature, relative humidity, wind speed, and horizontal wind vector components, u and v.

5.1 Mean Difference

$$MD = \frac{\sum_{j=l}^{m} \sum_{i=l}^{m} \left(\chi_{p,i,j} - \chi_{o,i,j} \right)}{mn} \tag{4}$$

Here the subscripts o and p represent observation and prediction, respectively. The subscript i represents the ith surface station, and the subscript j the jth forecast day. n is the number of surface stations, and m the total number of forecast days. A nonzero MD indicates bias. For instance, if the MD value is positive, it indicates that the model tends to over-forecast.

5.2 Mean Absolute Difference

$$AD = \frac{\sum \sum \left| \chi_{p,i,j} - \chi_{o,i,j} \right|}{mn} \quad . \tag{5}$$

5.3 Root Mean Square Error (RMSE)

$$RMSE = \sqrt{\frac{\sum_{j=1}^{m} \sum_{i=1}^{n} \left(\chi_{o,i,j} - \chi_{o,i,j} \right)^2}{mn}} \quad . \tag{6}$$

Good agreements between observation and forecast are, in general, related to smaller values of AD and RMSE.

5.4 Root Mean Square Vector Error (RMSVE)

$$RMSVE = \sqrt{\frac{\sum \sum [\left(u_{o,i,j} - u_{o,i,j} \right)^2 + \left(v_{o,i,j} - v_{p,i,j} \right)^2]}{mn}} \quad . \tag{7}$$

This parameter measures the differences of both wind speed and direction. Again, good agreements of wind vectors are related to small values of the RMSVE.

5.5 Correlation Coefficient

$$CC = \frac{\sum_{i=1}^{m}\sum_{j=1}^{n} y_{o,i,j}\, y_{p,i,j}}{\sqrt{\sum_{i=1}^{m}\sum_{j=1}^{n} y^2{}_{o,i,j} \sum_{i=1}^{m}\sum_{j=1}^{n} y^2{}_{p,i,j}}} \quad . \tag{8}$$

Here

$$y_{o,i,j} = x_{o,i,j} - \overline{x_o} \, , \tag{9}$$

and

$$y_{p,i,j} = x_{p,i,j} - \overline{x_p} \quad , \tag{10}$$

and $\overline{x_o}$ and $\overline{x_p}$ are the means of observed and forecast values, respectively.

6. BFM Validation Results

6.1 Statistical Parameters at Different Forecast Periods

Tables 3–10 show computed statistical parameters of surface meteorological parameters using BFM calculated and observed values. No statistical parameters are calculated for wind parameters for the Pakistan model domain due to the lack of surface observations.

6.2 Scatter Diagrams of Model Forecast Against Observations

The following scatter diagrams (Figures 4–10) are obtained by plotting all the data for all forecast periods and days. As can be seen, there is no comparison made for forecast periods beyond 18 hr, and no comparison was made for wind components for the Pakistan model domain.

As noted before, it is unfortunate that there are not enough observed data of wind speed and direction over the Pakistan model domain to make statistical comparison with BFM forecast data. Even for the Iranian model domain, comparisons could not be made for a forecast period beyond 18 hr. As can be seen from Tables 3 and 4 and Figures 4 and 5, there are good agreements for temperature between the BFM forecasts and surface observation for both model domains, with the CC values greater than 0.8. The MD values in Tables 3 and 4 show that the BFM slightly underforecasted temperature values.

For relative humidity forecasts, the CC value of 0.65 for the entire data set over the Iran model domain should be regarded as good, considering the lack of input data for model initialization over this region. Note that for this study, there were no upper air-sounding data used. In a

Table 3. Statistical parameters for temperature (C) over the Iran model domain.

Forecast Period (hr)	Number of Observations	MD	AD	RMSE	CC
0	53	−.98	3.24	4.92	.81
3	95	−1.44	3.30	4.92	.81
6	91	−.96	3.14	3.86	.81
9	27	−2.02	3.65	4.70	.71
12	47	−2.46	2.68	4.70	.75
15	32	−4.25	4.39	5.34	.72
18	5				
21	0				
24	1				
Entire period	351	−1.65	3.27	4.64	.81

Table 4. Statistical parameters for temperature (C) over the Pakistan model domain.

Forecast Period (hr)	Number of Observations	MD	AD	RMSE	CC
0	10	−1.79	1.86	2.90	.94
3	37	3.44	3.95	5.15	.81
6	36	2.46	2.94	3.42	.84
9	14	.51	3.05	3.61	.89
12	4				
15	11	1.29	1.79	2.26	.85
18	7				
21	1				
24	0				
Entire period	120	−1.79	1.86	2.90	.94

similar validation study of the BFM over model domains in the United States, the CC for dew point temperature between forecast and observation were 0.78 for the Colorado area, 0.44 for Washington, and 0.26 for Florida.[3]

For wind parameters (speed and u and v), the values of the MD are slightly negative, implying that the BFM tends to underforecast the magnitudes of wind parameters (see Tables 7 and 8 and Figures 8–10). In the study over model domains in the United States, the values of RMSVE were about 3 m/s or smaller throughout the 24-hr forecast period.[4] In this study, as can be seen in Table 10, the RMSVE is about 4 m/s. The CC values of this study are also slightly smaller than those over the model domains in the United States.

Table 5. Statistical parameters for relative humidity over the Iran model domain.

Forecast Period (hr)	Number of Observations	MD	AD	RMSE	CC
0	53	1.5	6.4	10.6	.83
3	95	-3.2	10.4	14.8	.67
6	91	-4.8	10.5	12.8	.68
9	27	-1.5	10.1	11.7	.49
12	47	.9	10.8	13.8	.23
15	32	3.2	11.3	15.4	.22
18	5				
21	0				
24	1				
Entire period	351	-1.8	9.9	13.4	.65

Table 6. Statistical parameters for relative humidity over the Pakistan model domain.

Forecast Period (hr)	Number of Observations	MD	AD	RMSE	CC
0	10	2.4	3.1	3.8	.99
3	37	-31.5	31.5	34.5	.25
6	36	-24.3	25.1	27.9	.30
9	14	-21.9	22.5	28.2	.60
12	4				
15	11	-27.0	27.0	28.0	.33
18	7				
21	1				
24	0				
Entire period	120	-24.0	25.1	29.1	.36

Compared to North America, the number of meteorological observations in the Western Asia is spatially and temporally limited. Therefore, the quality of NOGAPS data, which is used for initialization and boundary data of the BFM, may be more important over western Asia than over North America. The present validation results may be partially attributed to the NOGAPS data over western Asia.

Table 7. Statistical parameters of wind speed (meters/second) over the Iran model domain.

Forecast Period (hr)	Number of Observations	MD	AD	RMSE	CC
0	39	-2.0	2.6	3.27	.37
3	53	-.7	1.8	2.4	.19
6	49	-.9	1.8	2.3	.32
9	15	-.4	2.3	3.0	.05
12	40	-.8	2.4	3.0	.14
15	19	-.8	1.3	1.6	.06
18	2				
21	0				
24	0				
Entire period	217	-.5	2.4	3.0	.35

Table 8. Statistical parameters of wind component u (meters/second) over the Iran model domain.

Forecast Period (hr)	Number of Observations	MD	AD	RMSE	CC
0	39	-.3	2.6	3.1	.60
3	53	.4	2.4	2.9	.35
6	49	.2	2.4	2.7	.35
9	15	-1.0	2.5	3.0	.46
12	40	-1.4	2.9	3.6	.51
15	19	.6	1.5	1.9	.37
18	2				
21	0				
24	0				
Entire period	217	-.1	2.5	3.0	.45

7. Comparisons of Surface Wind Analysis Data of the MM5, AVN, and NOGAPS

Surface wind analysis data at 00 and 12 UTC by the MM5, AVN and NOGAPS obtained from the Navy through the internet contain the gridded data covering the following areas and days:

Table 9. Statistical parameters of wind component v (meters/second) over the Iran model domain.

Forecast Period (hr)	Number of Observations	MD	AD	RMSE	CC
0	39	-.3	2.4	3.0	.47
3	53	-1.3	2.2	2.7	.40
6	49	-.9	2.4	3.0	.35
9	15	.6	2.8	3.3	.20
12	40	.3	3.0	3.7	.35
15	19	-.2	1.3	2.5	.1
18	2				
21	0				
24	0				
Entire period	217	-.5	2.4	3.0	.35

Table 10. RMSVE (meters/second) wind vector over the Iran model domain.

Forecast Period (hr)	Number of Observations	RMSVE
0	39	4.3
3	53	3.9
6	49	4.2
9	19	4.0
12	40	4.9
15	19	3.3
18	2	
21	0	
24	0	
Entire period	217	4.3

- MM5: 24° E – 75° E, and 16.4° N – 58.4° N with 0.403° grid spacing, and
- 9-day data from 15 October to 25 October 2001.
- AVN and NOGAPS: 53° E - 80° E, and 21° N - 45° N, with 1° grid spacing, and
- 17-day data from 15 October to 30 November.

Tables 11–13 are statistical parameters calculated for surface wind analysis data against observed data for the MM5, AVN, and NOGAPS, respectively. The values of RMSVE are given in the description of each table.

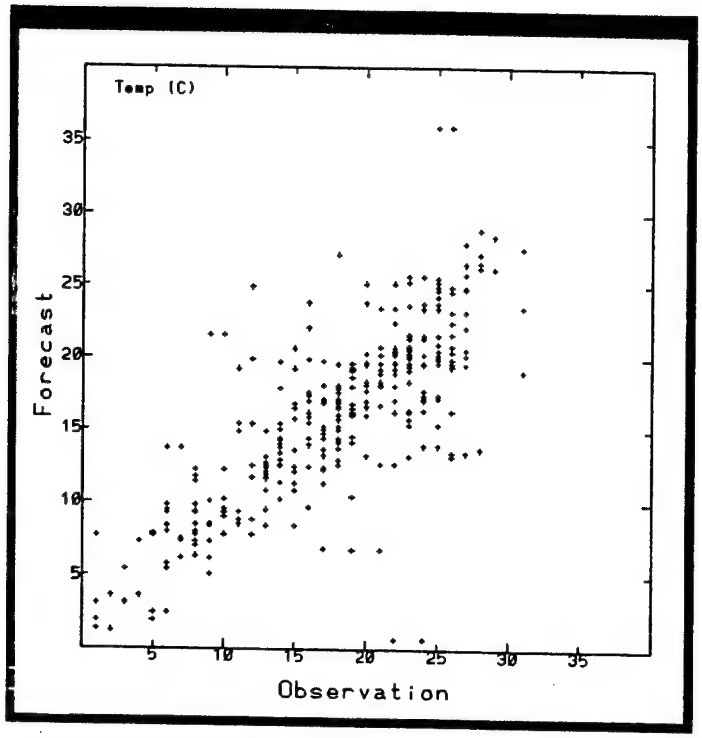


Figure 4. Scatter diagram of BFM vs. surface observation for temperature over the Iran model domain.

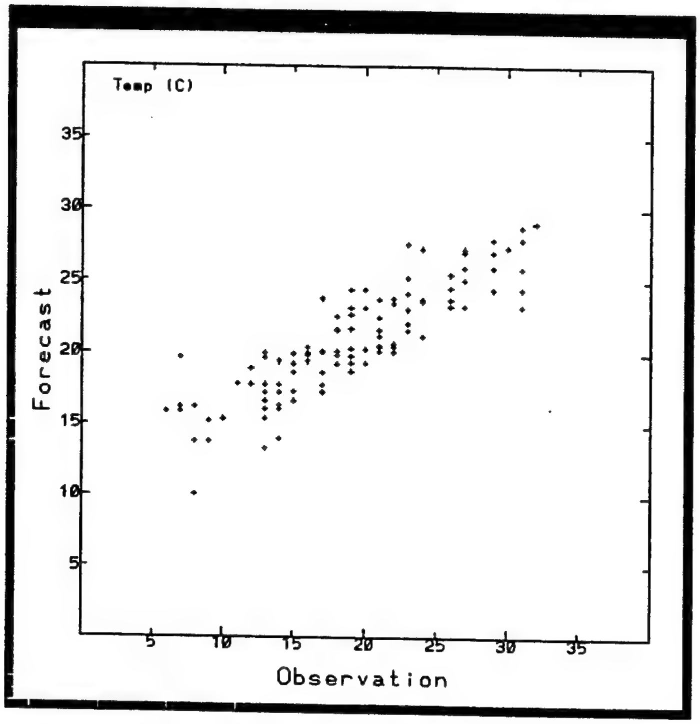


Figure 5. Scatter diagram of BFM vs. surface observation for temperature over the Pakistan model domain.

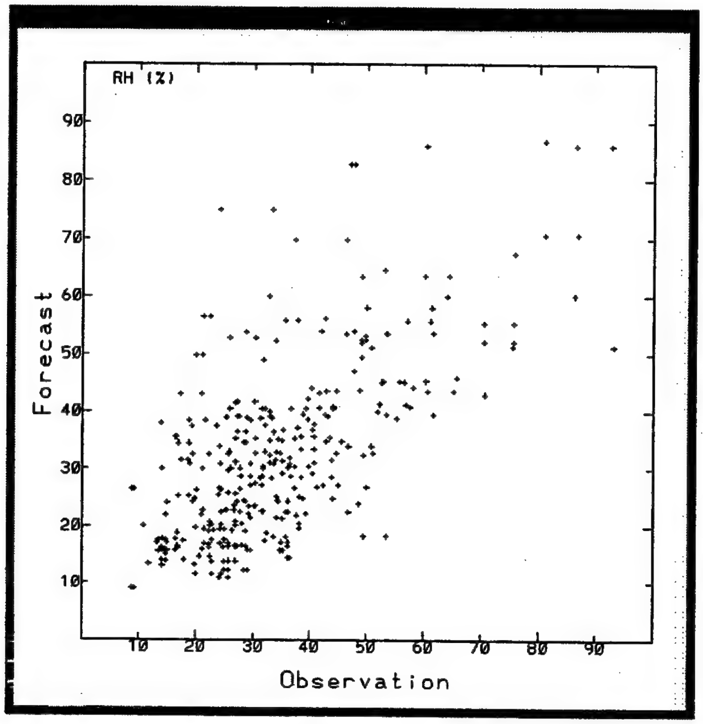


Figure 6. Scatter diagram of BFM vs. surface observation for relative humidity over the Iran model domain.

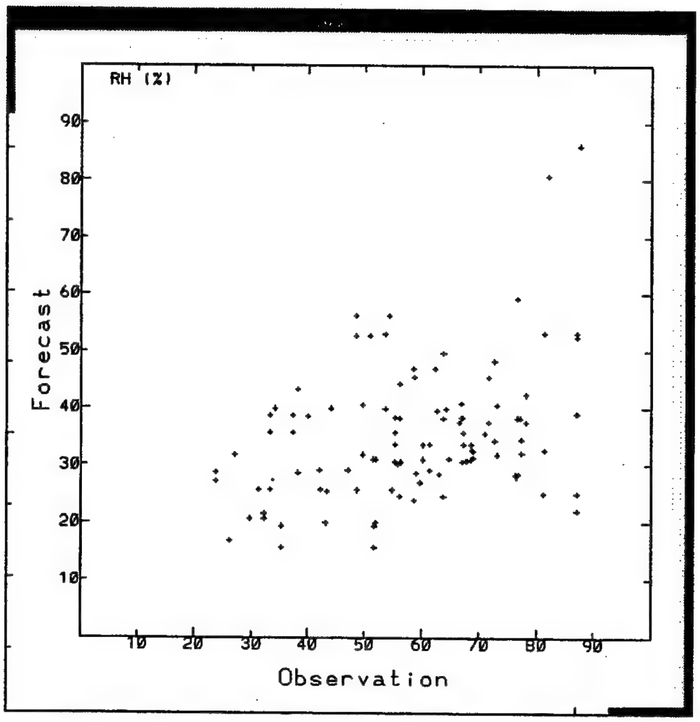


Figure 7. Scatter diagram of BFM vs. surface observation for relative humidity over the Pakistan model domain.

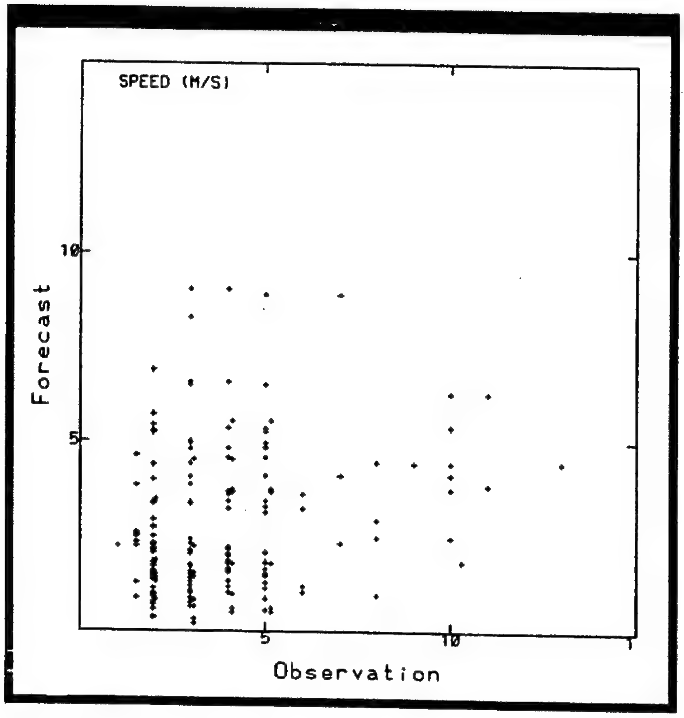


Figure 8. Scatter diagram of BFM vs. surface observation for wind speed (meters/second) over the Iran model domain.

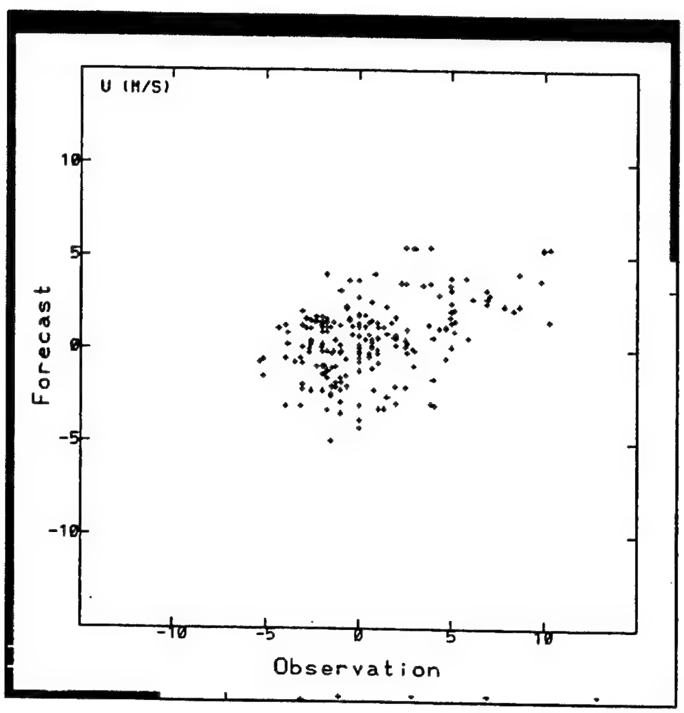


Figure 9. Scatter diagram of BFM vs. surface observation for wind vector component u (meters/second) over the Iran model domain.

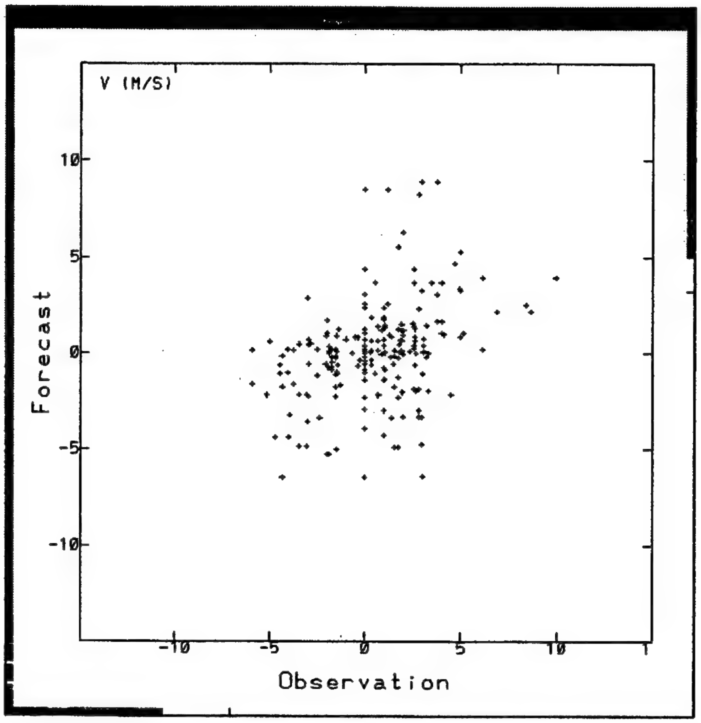


Figure 10. Scatter diagrams of BFM vs. surface observation for wind vector component v (meters/second) over the Iran model domain.

Table 11. Statistical parameters of wind speed and u and v for surface wind analysis data by the MM5; RMSVE = 4.0 m/s.

	No. of data	MD	AD	RMSE	CC
Speed (m/s)	473	-.5	1.7	2.5	.42
u	473	.2	1.7	2.6	.62
v	473	.4	2.0	3.1	.63

Table 12. Same as Table 11, except for AVN; RMSVE = 3.3 m/s.

	No. of data	MD	AD	RMSE	CC
Speed (m/s)	253	.8	1.9	2.6	.25
u	253	.4	1.4	2.2	.58
v	253	.4	1.7	2.5	.55

Table 13. Same as Table 11, except for NOGAPS; RMSVE = 4.0 m/s.

	No. of data	MD	AD	RMSE	CC
Speed (m/s)	233	-.9	1.6	2.1	.45
u	233	1.3	1.8	2.7	.47
v	233	1.1	1.9	2.9	.42

Scatter diagrams of model analysis data of wind speed and u and v are shown in, respectively, Figures 11–13 for the MM5, Figures 14–16 for AVN, and Figures 17–19 for NOGAPS.

Fairly good statistical values previously shown should have been expected because surface observation data used for comparison might have been used to derive surface analysis data by these models.

It is cautioned that the statistical results obtained for these models, the MM5, AVN, and NOGAPS, shown in this section should not be used to compare quantitatively to those of BFM shown in the previous section, or those of other models, because of the following reasons:

- Model domain size and grid are different from each other,
- Numbers of surface data used for comparison are different, and
- Numbers of forecast days are different.

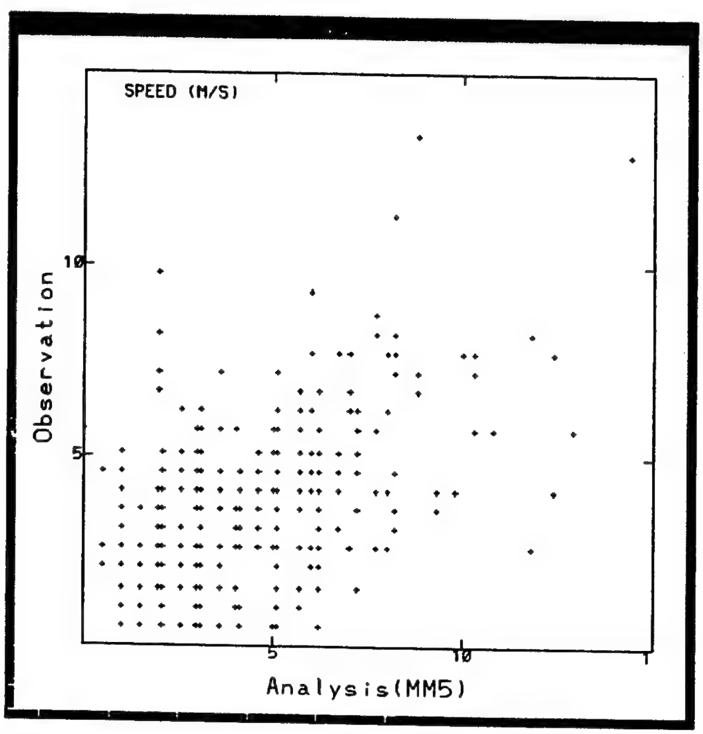


Figure 11. Scatter diagram of surface wind speed analysis data by the MM5 against observation.

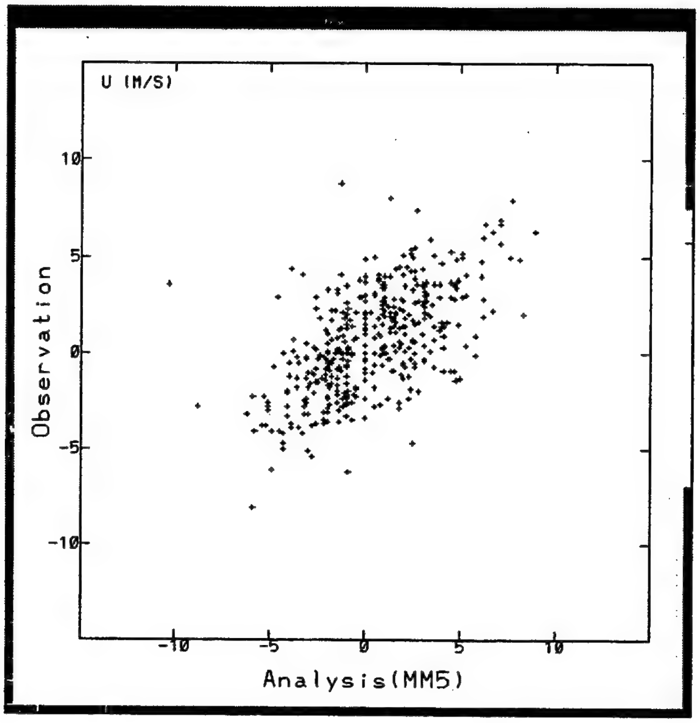


Figure 12. Same as Figure 11, except for u.

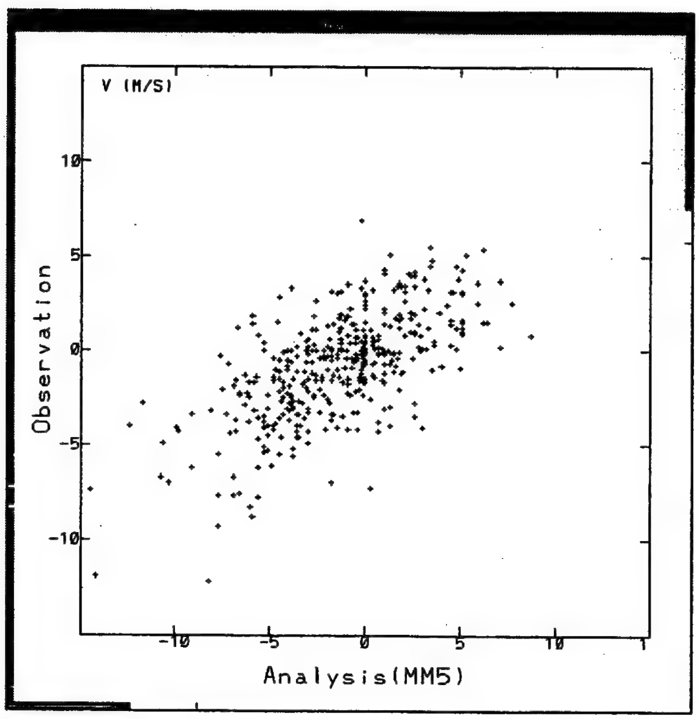


Figure 13. Same as Figure 11, except for v.

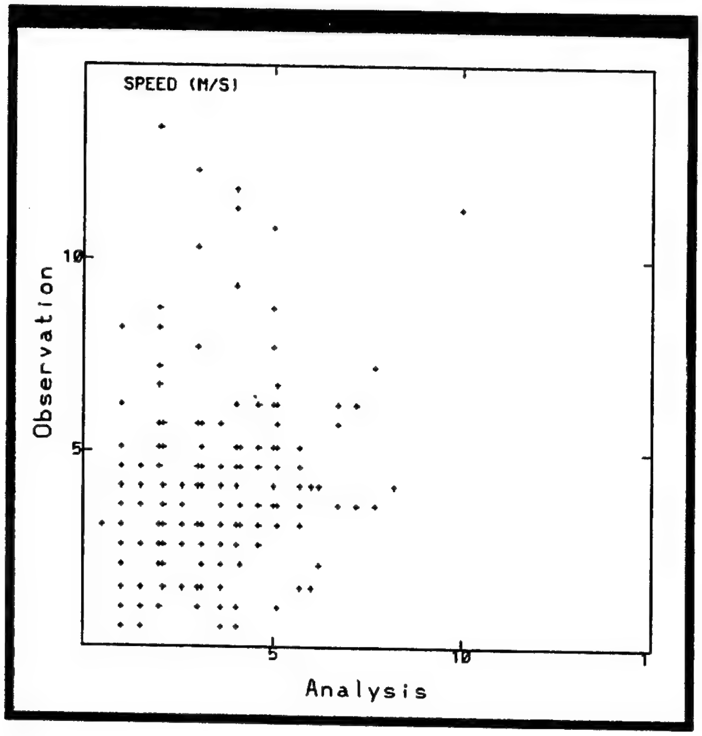


Figure 14. Scatter diagram of surface wind speed analysis data by AVN against observation.

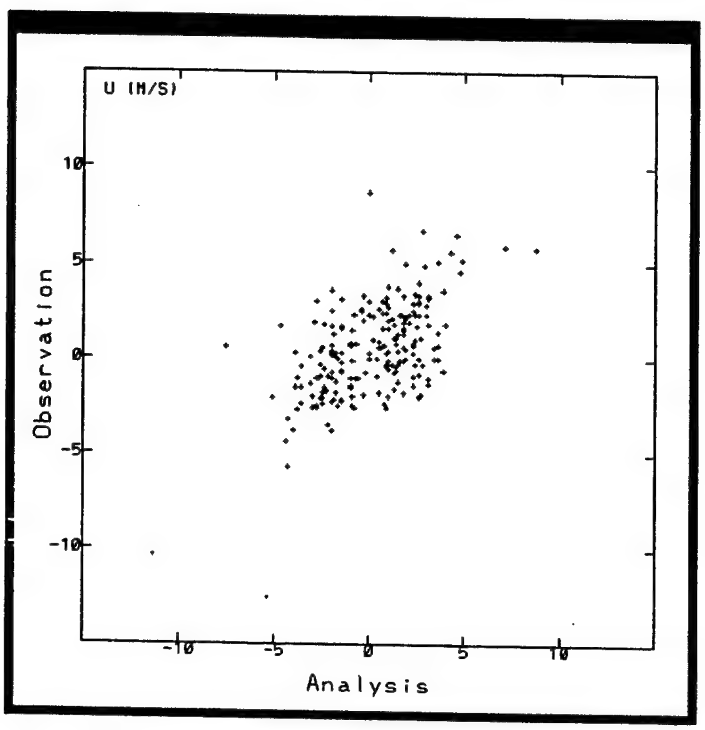


Figure 15. Same as Figure 14, except for u.

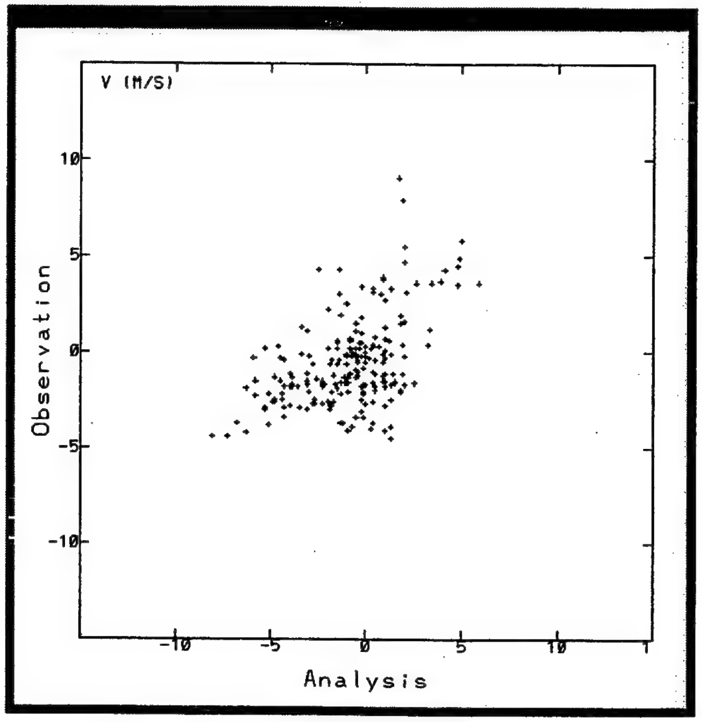


Figure 16. Same as Figure 14, except for v.

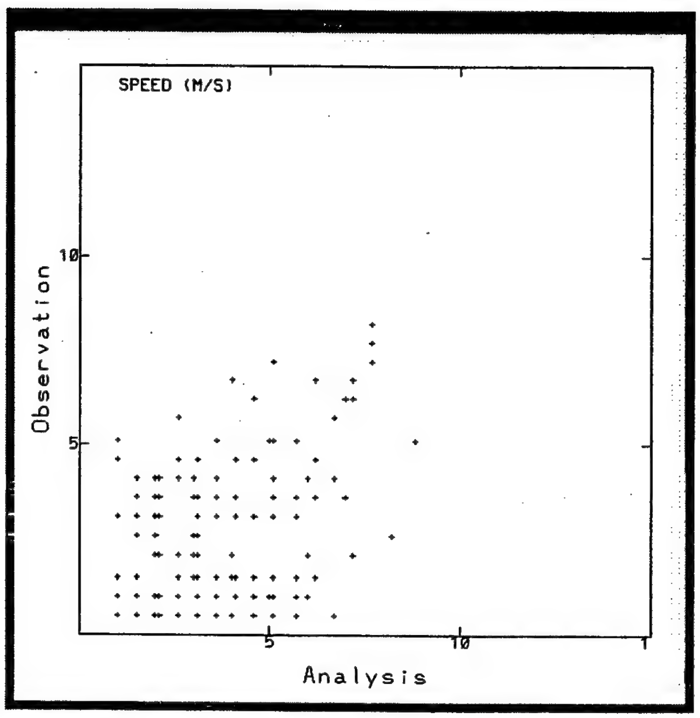


Figure 17. Scatter diagram of surface wind speed analysis data by NOGAPS against observation.

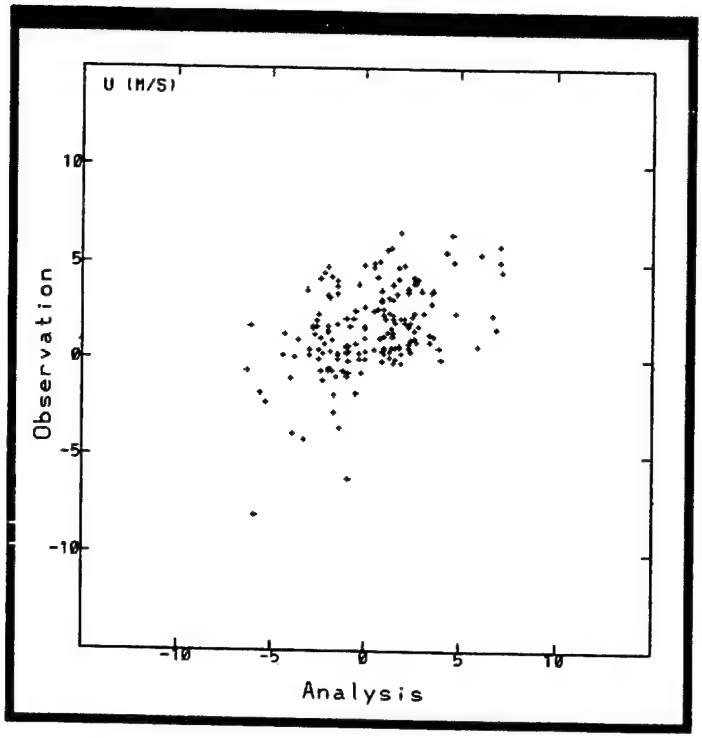


Figure 18. Same as Figure 17, except for u.

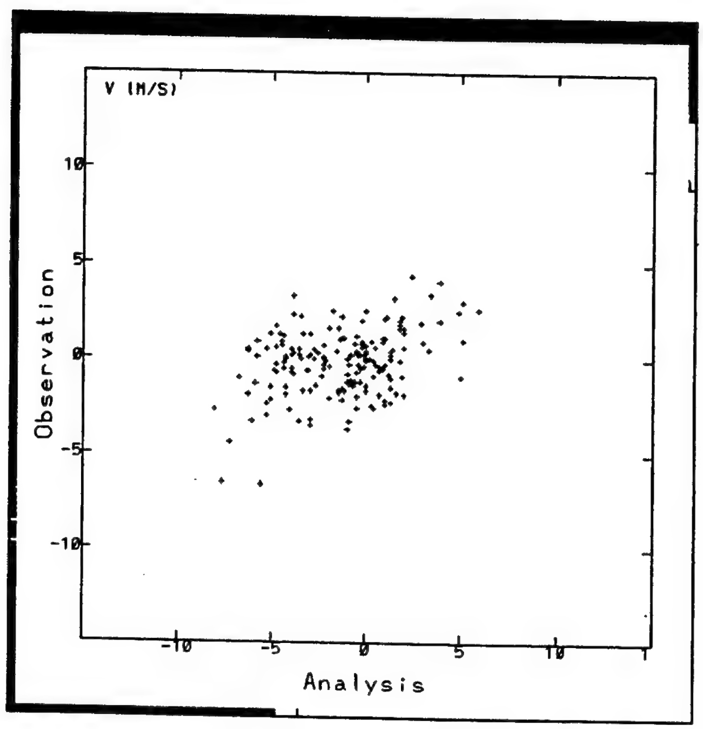


Figure 19. Same as Figure 18, except for v.

8. Summary and Consideration

After the start of the U.S. military operation over Afghanistan, a validation study of the BFM in operational mode over the western Asian region became urgently necessary.

It would have been ideal to run the BFM over Afghanistan, but lack of the availability of meteorological observation data forced the selection of model domains adjacent to Afghanistan. The current version of BFM on the U.S. Army IMETS ABCS_6_2_1_0 was run over Iran and Pakistan model domains and evaluated by comparing surface forecast data to surface observation data. Unfortunately, the availability of observation data was far less than ideal. There were very few upper air-sounding data which could be used to initialize the BFM and to compare to forecast data. For surface data, there were seven stations in the Iran model domain and only one station in the Pakistan model domain. Thus, it is emphasized that the results obtained in this study should be regarded at best as qualitative.

- For surface temperature, the BFM forecast data produced good agreement with observed data with the CC of 0.81 for the entire data set for the Iran model domain.
- Relative humidity forecasts were also fairly well done by the BFM, with the CC of 0.65 for the Iranian model domain.
- The BFM showed the tendency of underforecasting wind speed throughout the entire forecast period, with the MD of –0.5 m/s for the Iran domain. Similarly, forecasted values of horizontal wind vector components u and v tended to be smaller than observed values. The CC for wind speed and u and v were, respectively, 0.35, 0.45, and 0.35 for data covering the entire study period over the Iran model domain.

Questions as to whether the statistical results over Iran can be applied to Afghanistan are difficult to answer. As shown in Table 1, terrain data over Afghanistan showed more complexities than the one over Iran, but not as complex as the one over Pakistan. Over the Pakistan model domain, temperature forecast data by the BFM showed fairly good agreement with observation, but based on only one station data. In a previous validation study of the BFM over different climatological and topographical areas in the United States (Colorado, Washington, and Florida), no significant differences in statistical parameters for surface wind parameters were obtained.[4]

Western Asia was, in general, not a good region to conduct mesoscale model validation studies because of the limited amount of observed meteorological data. Ideally, the validation study should have been done over the areas with complex topographical feature where a large number of surface and upper air data were regularly available. For instance, the Utah area in the United States may be a proper region to conduct such a study with an existing mesoscale meteorological observation network and complex topographical features.

Surface wind analysis data calculated by the MM5, AVN, and NOGAPS over western Asia were also compared with observed data, showing slightly better statistical results than the BFM over the Iranian model domain. However, intercomparisons of different models operated over different model domains and periods were not valid. The results should be regarded at best as qualitative.

Another consideration must be taken into account when comparing observed parameters such as wind speed and vector components, temperature, and humidity to model calculations of these parameters. Observed data typically represent brief (~10 min) averages of each parameter taken from instruments which require regular calibration and tend to characterize the time period at the top of the hour. Model calculations, on the other hand, are more representative of mean values of the parameters over larger temporal and spatial scales.

List of Acronyms

AD	Absolute difference
AVN	Aviation Model
BFM	Battlescale Forecast Model
CC	Correlation coefficient
IMETS	Integrated Meteorological System
MD	Mean Difference
MM5	Mesoscale Model Version 5
NOGAPS	Navy Operational Global Atmospheric Prediction System
NORAPS	Navy Operational Regional Atmospheric Prediction System
RMSE	Root mean square error
RMSVE	Root mean square vector error
UTC	Universal time coordinate

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14. ABSTRACT

The current version of the Battlescale Forecast Model (BFM) on the U.S. Army Integrated Meteorological System was evaluated by comparing the model's forecast data with observed meteorological data. Two model domains adjacent to Afghanistan, Iran, and Pakistan were selected to run the BFM for 24-hr forecast periods in operational mode. Due to the limited number of observation stations and data, the results obtained in this study should be regarded as qualitative. The following findings were obtained: For surface temperature, the BFM forecast data were in good agreement with the surface observation data for both Iran and Pakistan model domains. Relative humidity forecast by the BFM was also in fair agreement with observation. The BFM showed the tendency to underforecast wind speed throughout the entire forecast period. Similarly, forecast values of horizontal wind vector components u and v tended to be smaller than observed values. Surface wind analysis data calculated by the MM5, AVN, and NOGAPS over western Asia were also compared with the observed data, showing slightly better statistical results than the BFM over the Iranian model domain. Statistical intercomparisons of different models operated over different model domains, grid configuration, and different initialization data were not valid comparisons. It is suggested that a validation study of the BFM be done over the area where a large number of surface and upper air data are regularly available and where topographical features are complex enough to generate diurnal wind patterns, such as Utah.

15. SUBJECT TERMS
mesoscale model, short-range forecast, western Asia, BFM

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